THE VIOLET CLOUDS OF MARS

N. B. Ibragimov, I. K. Koval'

ABSTRACT. Results are given of photometric investigations of Martian violet clouds based on observations carried out during 1958 - 1961, 1965, and 1969. Photometric data for the former three oppositions were obtained at the Astronomical Observatory of the Ukrainian Academy of Sciences. In 1969 the observations were made with the 2-meter reflector of the Shemakha Observatory using a grating spectrograph (dispersion 30 Å/mm). Monochromatic albedo was determined for an intense cloud observed near the terminator in the southern hemisphere on April 24, 1969. The values of optical thickness found in this investigation permitted the Junge parameter ($\nu = 3.9$) to be determined and a conclusion to be made that the violet cloud consists mainly of small particles.

The brightest violet clouds usually are seen at the eastern and western limbs of Mars when observations are in the shortwave region of the spectrum. They were first observed by Wright, the American astronomer in 1924, and since that time these formations have been under systematic observation by many observatories around the world. /3*

Slipher's photographic atlas [1] contains many excellent pictures of Mars, obtained over the past decade. This material leads to the conclusion that the violet clouds are not always seen. These clouds did not appear, except on rare occasions, during the favorable 1956 opposition. However, during most of the "ordinary" oppositions these formations cover up to 10 percent of the area of the visible disk of Mars, and sometimes are comparable in brightness to the polar caps.

Study of the activity of violet clouds in terms of heliocentric longitude of the planet has attracted the attention of astronomers for a comparatively long time, but not until 1958 [2], and again in 1961 [3], were the photometric characteristics of these formations obtained.

Violet clouds along the edges of the equatorial diameter of the Martian disk were a routine phenomenon in September - November 1958. The bright streak located along the equator and connecting the intense limb clouds was seen quite

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* Numbers in the margin indicate pagination in the foreign text.

well at times in the blue and violet rays.

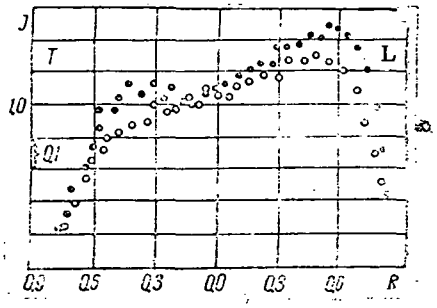

Figure 1. Photometric section of the Martian disk near the equator from 1958 photography (λ_{ef} = 3900 Å). The dots are the section passing through the violet clouds, the circles the comparison section (phase angle 21°).

Figure 1 is an example of the photometric sections parellel to the planet's equator and intersecting the violet clouds at the eastern and western limbs of the image. The section passes through along the bright streak mentioned, and this makes it possible to evaluate the contrast created by this streak with its surroundings. This contrast is very weak, a maximum of 5 to 7 percent for 3900 Å. The comparison section (the dots in Figure 1) was constructed by averaging the measurements along two directions inclined to the equator at an angle of about 15° because the clouds were located in the latitudinal direction quite distant from the equator (about ±10°).

TABLE 1. PHOTOMETRIC CHARACTERISTICS OF VIOLET CLOUDS FROM 1958 OBSERVATIONS

Date	λ micron	Terminator (W)			Limb (O)		
		ϱ_1	ϱ_2	$\Delta\varrho$	ϱ_1	ϱ_2	$\Delta\varrho$
October 8/9	0.40	0.102	0.077	0.025	0.118	0.110	0.008
„ 13/14	0.40	103	088	015	128	111	017
„ 14/15	0.40	085	050	033	128	112	016
„ 21/22	0.36	060	050	010	078	070	008
„ 28/29	0.36	058	048	010	067	054	012
November 4/5	0.40	107	103	004	125	115	010
„ 5/6	0.40	113	101	012	128	118	010
„ 9/10	0.40	103	077	026	119	110	009

Table 1 lists the results of 1958 violet cloud photometry. The relative measurements have been converted into absolute with respect to 1956 data. This is why the table lists the apparent albedo for the section of the planet near the cloud, ϱ_2, and for the cloud itself, ϱ_1. These data, obtained for different longitudes of the central meridian of Mars, show that the violet clouds are in no way connected with the details of the Martian surface, particularly the seas.

Yet the mean data (Table 2) show that a cloud on the terminator side (the setting limb) has a greater relative brightness than one on the limb side.

TABLE 2. MEAN PHOTOMETRIC CHARACTERISTICS OF VIOLET CLOUDS FROM 1958 OBSERVATIONS

λ microns	Terminator (W)		Limb (O)	
	contrast	Δϱ	contrast	Δϱ
0.36	0.16	0.010	0.13	0.09
0.40	0.17	0.18	0.11	0.012

Monochromatic sections passing through the Wright clouds [3] were obtained from spectrophotometry in 1960 - 1961. Reference [3] cites detailed data on /4 the distribution of brightness along the Martian equator, showing that the clouds begin to be perceived photometrically near 4800 Å. Figure 2 shows three photometric sections passing through the violet clouds and showing the increase in the cloud-background contrast on the shortwave side. Just as in 1958, the cloud on the setting limb was relatively brighter at this time.

The Wright clouds were not very bright in 1963, but were quite intense during the period of opposition in 1965 [4], standing out sharply on the photoelectric sections. The cloud on the setting limb was relatively brighter at this time. Figure 3 shows the photoelectric sections obtained on 6-7 April 1965, with a filter (maximum band pass about 3550 Å), and the fact that the cloud-continent contrast on the setting limb is 15 percent.

The mean photometric characteristics of the violet clouds, from 1958, 1961, and 1965 observations, are

λ, micron	0.36	0.40	0.45	0.50
k, W	0.20	0.20	0.17	0.04
k, O	0.13	0.10	0.07	0.03
ϱ_1, W	0.060	0.075	0.126	0.137
ϱ_2, W	0.050	0.067	0.118	0.128

The apparent albedo values for the clouds, ϱ_1, and for the adjacent continent, ϱ_2, show that the spectrum difference $\varrho_1 - \varrho_2$ changes little, although the contrast falls off quickly toward the red end of the spectrum.

The spectral limit of visibility of the clouds changes with their intensity (density). It usually puts in an appearance near 4500 Å, but at times of greatest development the visibility boundary shifts to the red end of the spectrum such that the presence of the clouds is photometrically perceptible near 5000 Å, /5 and their brightness near 3500 Å sometimes can be compared to the brightness of the polar caps.

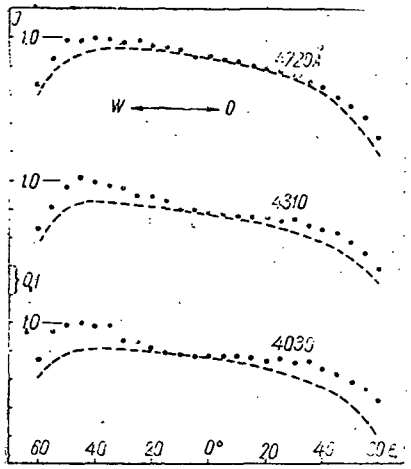

Figure 2. Photometric sections of the Martian disk near the equator from spectrograms obtained on 6-7 January 1961. Angles of reflection are plotted on the x-axis, relative intensities on the y-axis.

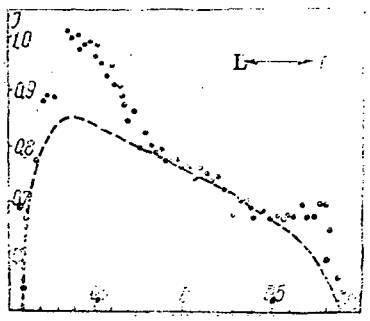

Figure 3. Photoelectric section of Martian disk near the equator, obtained 6-7 April 1965. The dashed line is the comparison section (continent). λ_{ef} = 3550 Å.

The mean size, and the number of particles in the cloud column, have been calculated from the 1958 and 1965 observations [5]. It was assumed that the refractive index of the particles was 1.5 (aerosol of the terrestrial atmosphere), that particle distribution by size was in accordance with Junge's law, and that the particles themselves were spherical. It was found that the particle radius was $r \approx 0.05$ micron, and that the number of particles was of the order of 10^{11} cm^{-2} for a mean observed cloud contrast near 4000 Å of 20 percent ($\tau \approx 0.1$).

Mars was observed in 1969 at the Shemakha Astrophysical Observatory of the Academy of Sciences of the Azerbaydzhan SSR in the Cassegrain focus of a 2-meter reflector. N. B. Ibragimov obtained scores of spectrograms of Mars with a dispersion of 30 Å/mm on Kodak OaF plates with an image scale of 7"/mm. The 24

April 1969, observations were made when the slit of the spectrograph was positioned along the chord of the planet's disk and intersected the south polar cap, the continent adjacent to it, and the intense cloud formation located near the terminator in the part of the southern hemisphere near the equator. We used the spectrograms obtained on that date to make a spectrophotometric study of the cloud formation. Photometry of the spectrograms was performed across, as well as along, the dispersion in the 3800-6600 Å region.

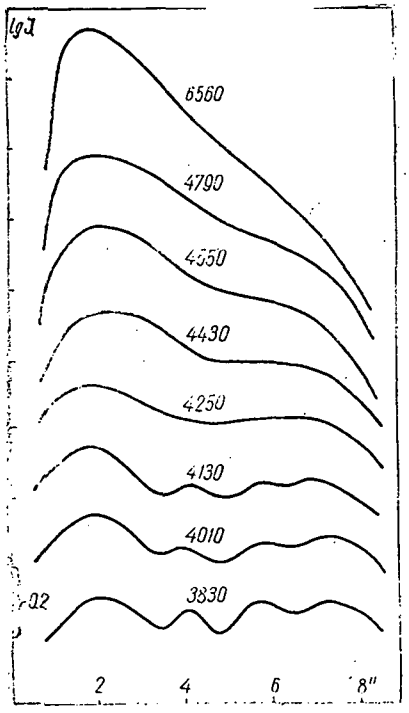

Figure 4. Photometric sections along the chord of the Martian disk intersecting the polar cap (left) and the cloud (right). Spectral observations of 24 April 1969, using the Shemakha Astrophysical Observatory's 2-meter reflector.

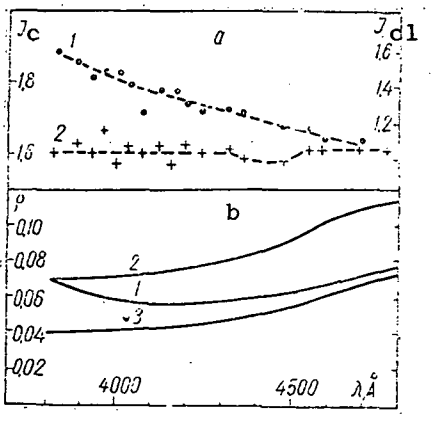

Figure 5. Photometric characteristics of a violet cloud from spectral observations on 24 April 1969.
a - cloud brightness (1) and south polar cap brightness (2) in terms of wavelength compared to continents;
b - monochromatic albedo of cloud (1), cap (2), and continents (3).

Figure 4 shows the transverse photometric section of one of the spectrograms obtained for the longitude of the central meridian of Mars near 150°. Logarithms of the intensity are plotted along the y-axis, and seconds of arc along the x-axis. As we see, the cloud becomes photometrically perceptible near 4800 Å, and near 3800 Å is comparable in brightness to the south polar cap. If the effect of

limb darkening (the phase angle at the time of observation was about 26°) is taken into consideration, and if the relative measurements obtained are made absolute in terms of the 1960 - 1961 observations [3], we obtain monochromatic values of cloud and south polar cap albedo as shown in Figure 5b. This figure shows that the cloud has a lower apparent albedo than does the polar cap, and only near 3800 Å are their albedoes comparable.

Figure 5a shows the brightness of the cloud and of the polar cap compared to /6
that of the continent. We see that the cap-continent contrast remains constant in the 3800 - 4800 Å region, whereas cloud brightness rises steadily toward the violet end of the spectrum. We further note that the data for the violet cloud observed on 24 April 1969, were photographed at the point of maximum cloud brightness (density), although (as will be seen from Figure 4) the structure of this formation becomes better defined with reduction in wavelength. Evidently a system of violet clouds with different densities was observed at the time of observation near the planet's terminator.

Let us attempt to use the data from the photometric observations of the violet clouds to determine some of the optical parameters of these formations.

Unfortunately, we cannot use the spectral observations made in 1969 at the Shemakha Astrophysical Observatory because the spectrophotometric chracteristics of the clouds obtained apparently were badly distorted by the influence of atmosphere dispersion because of the large south declination of Mars at the time of observation. We should point out that unfortunately the Cassegrain system of the 2-meter reflector at the Shemakha Astrophysical Observatory does not include positional rotation of the spectrograph to permit observations with minimum influence exerted by atmospheric dispersion. This comment applies in part as well to the 1960 - 1961 observations, but these were made with Mars high enough above the horizon and were limited to a minimum wavelength at 0.4 micron.

Let us, therefore, use the data from the 1958, 1960 - 1961, and 1965 observations to determine the optical parameters of the violet clouds. The measured cloud-adjacent mainland contrasts contained in reference [2-4] were recalculated for a phase angle of $\alpha = 10°$ and a value of the cosine of the angle

of reflection for light of $\zeta = 0.71$. We used for this purpose the calculated /7 data on the distribution of brightness along the equator of Martian intensity for different α as set forth in reference [8].

Table 3, which lists the mean spectral values for the brightness coefficient for the western and eastern clouds, also lists the values for the scattering indicatrix of light, and the optical thickness for "average" Martian atmosphere, according to reference [6]. There is very little change in indicatrix values, according to data on the spectrum in reference [6], so we took a mean value of $\chi_a(\pi - \alpha) = 0.65$ for the region considered.

TABLE 3. MEAN SPECTRAL VALUES OF THE BRIGHTNESS COEFFICIENT FOR THE WESTERN AND EASTERN CLOUDS

λ, micron	0.36		0.40		0.45		0.50	
	W	O	W	O	W	O	W	O
$\bar{r}_0$	0.095	0.083	0.108	0.087	0.128	0.112	0.150	0.131
$\bar{r}_a$	0.078	0.71	0.091	0.076	0.118	0.104	0.144	0.126
$\chi_a(\pi-\alpha)$	0.65		0.65		0.65		0.65	
τ_a	0.064		0.048		0.038		0.032	

Let us use known expressions for the brightness coefficient, without including multiple scattering

$$r(\eta, \zeta, \alpha) = \frac{\omega\chi(\pi-\alpha)}{4(\eta+\zeta)}\left[1 - e^{-\tau\left(\frac{1}{\eta}+\frac{1}{\zeta}\right)}\right] + f(\eta, \zeta)\, e^{-\tau\left(\frac{1}{\eta}+\frac{1}{\zeta}\right)} \qquad (1)$$

where

ω is the probability of survival of a quantum;

$\chi(\pi - \alpha)$ is the scattering indicatrix of light in the atmosphere;

α is the planet's phase angle;

τ is the atmosphere's optical thickness;

η, ζ are the cosines of the angles of incidence and reflection of light;

f is the brightness coefficient for the planet's own surface.

From two such equations, written for the center of the cloud, and for the point of comparison (with the same η and ζ values), eliminating $f(\eta, \zeta)$, and taking $\omega = 1$, we obtain

$$e^{-\tau_0 c} = \frac{\varkappa_0 - r_0}{\varkappa_a - r_a - \tau(\varkappa_0 - \varkappa_a)e^{-\tau_a c}}, \qquad (2)$$

where

$$c = \frac{1}{\eta} + \frac{1}{\zeta}, \quad \varkappa = \frac{\chi(\pi-\alpha)}{4(\eta+\zeta)}.$$

Here the subscript a is the atmosphere and o is the cloud, and the optical thickness in Eq. (1), written from the center of the cloud, is equal to $\tau = \tau_a + \tau_o$.

Let us assume that the shape of the particles contained in the cloud is spherical, and that the density of particle distribution by size is determined by Junge's law.

$$dN = \frac{\bar{C}}{r^{\nu+1}} dr,$$

where

dN is the number of aerosol particles, the radii of which are in the limits r to r + dr;

C is the normalization constant;

ν is the so-called Junge distribution parameter.

Junge's law is well justified for terrestrial aerosols, as special research has shown (see reference [7] for a survey of the literature apropos of this). In this case the spectral behavior of the optical thickness of the aerosol is determined by $\tau_\lambda = b\lambda^{-n}$, where b is some constant, and $n = \nu - 2$. The magnitude ν lies in the limits $2 < \nu < 6$, and the larger ν, the greater part the smaller particles have in scattering the light. /8

τ_{01}, n, and $\varkappa_0$ are determined by taking $\lambda_1 = 0.36$ micron, $\tau_0 = \tau_{01}$, $\varkappa_{0\lambda} =$ = constant, and $\tau_{0\lambda} = (\frac{\lambda}{\lambda_1})^{-n}\tau_{01}$, using Eq. (2) and the data listed in Table 4. The results, obtained using a "Promin'" electronic computer, are $\varkappa_0 = 0.15$ or $\varkappa_0(\pi - \alpha) = 0.77$, $n = 1.9$ for the western and eastern clouds.

The following values were obtained for the optical thickness of the clouds

λ, micron	0.36	0.40	0.45	0.50
$\tau_{0\lambda}$, W	0.073	0.060	0.048	0.038
$\tau_{0\lambda}$, O	0.057	0.046	0.37	0.030

The values n = 1.9, or $\nu = 3.9$, we obtained within the framework of the assumptions used bespeak the big part played by the fine aerosol in the violet cloud.

The mean values of $\tau_{0\lambda}$ for the violet clouds we found for 1958, 1960 - 1961, and 1965 evidently are the low limit because the atmospheric image tremor of the planet always reduces the surface brightness of comparatively small disk

details. It would thus seem that the cloud-adjacent continent contrasts we measured were most likely too low. Moreover, the 1959 observations evidently provide a greater relative violet cloud intensity than was the case in 1958-1965.

Thus, the rough approximation for the violet clouds of Mars is $\tau(0.36 \text{ micron}) \approx 0.1$ when $\nu = 3.9$. Comparing this ν value with the mean value $\nu = 4.25$ for a "homogeneous" Martian atmosphere [6], we can conclude that the mean size of the particles in the violet cloud, within the context of the assumption we have made, is very close to the mean size of the aerosol particles in the homogeneous Martian atmosphere. It can be supposed, naturally, that the violet clouds are "bunches" of aerosol particles constantly present in the Martian atmosphere and creating the known effect of violet haze.

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